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DOMESTIC HEATING AND AIR CONDITIONING

Introduction

Anyone contemplating the construction of a dwelling house should consider how to heat it, how to insulate it, and what to do, if anything, to make it cooler in summer. Insulation is mentioned here on account of its direct connection with winter heating and summer air conditioning. The better the insulation, the simpler and smaller the heating or the cooling apparatus can be.

At one time, building a house was regarded as one problem and heating it as another, but at present the relation between heating, air conditioning and structure, including insulation, is receiving more consideration. The house designer should consider the heating problem just as the heating engineer must consider the form and structure of the house. This is not to say, however, that these problems are in any case capable of simple or exact solution. Present day knowledge of some phases of the matter is general only and many decisions must be based on the experience or judgment of the builder, heating contractor or owner. If an owner has a predilection for a particular kind of structure and heating system, be the latter steam, hot water or warm air, there is no reason why he should not follow it because the probability is good that the combination can be made to perform successfully since this largely depends on proper installation and operation of equipment of proper size.

The National Bureau of Standards does not attempt to gather either statistical or experimental data on the various makes of heating or air conditioning equipment on the market for the purpose of comparing their relative merits. A considerable number of manufacturers are in the business of producing such equipment and changes in design or model are so common that comparative data would probably be obsolete before they could be put to use. In addition to this, the performance of such apparatus is so dependent upon its proper installation, operation and maintenance that make and type are probably no more important than the care and skill used by the installers and operators.

Insulation

Information and references on the insulation of buildings are contained in National Bureau of Standards Letter Circulars Nos. 465 (Aluminum Foil Insulation) and 471 (Insulation) and in Circular of the Bureau of Standards C376 (Thermal Insulation of Buildings). The Letter Circulars can be obtained from the National Bureau of Standards on request. Circular C376 is available from the Superintendent of Documents, Government Printing Office, Washington, D. C., at five cents per copy.

The question of how much insulation to put into houses, or, more specifically, how much money to invest in insulation often arises. Some authorities consider it worth while to estimate the useful life of a house as well as possible and to proportion insulation cost and probable saving in heating cost so that the insulation will pay for itself within a given time.

Another approach, proposed by R. K. Thulman in a paper entitled "A Proposed Basis for Establishing Minimum Requirements for Insulation" presented before the National Mineral Wool Association in May 1940, is to consider comfort rather than cost as the determining factor. Since a house with warm walls has a more uniform temperature distribution than one with cold walls, it is proposed to install sufficient insulation so that the inside wall surface temperature will not be below some given temperature (65°F was suggested) when the house is heated to 70°F on a day when the outdoor temperature is as cold as the heating system is designed for.

Either of these methods leads to the use of less insulation for a warm climate than for a cold one. Neither considers the amount of insulation which should be installed in warm localities to keep the heat out. All we can say in this respect is that insulation in the ceiling or roof structure will aid materially in keeping the house cool in hot weather.

In and around Washington, D. C. many houses are insulated in the ceiling with from two to three inches of fill material, poured or placed between the joists. Side walls are often insulated with material available on the market in the form of blankets or batts, about two inches thick, covered with treated moisture-and-vapor-proof paper. Such material is sometimes installed in the roof structure when it is desired to warm the attic and when this is done, a space ventilated with outdoor air is essential between the insulating material and the roof boards, for reasons which are discussed in the next section, on vapor barriers.

Vapor Barriers

Water vapor barriers are now considered essential to insulat ed walls. Since houses are generally kept closed in winter for warmth, cooking and washing operations, which liberate water vapor, or the use of humidifiers make the amount of water vapor per cubic foot of air much greater on the inside of the house than it is out of doors.

This water vapor has a tendency to "migrate" through porous or hygroscopic walls from the inside toward the outside of a house and if it reaches a portion of the wall where the temperature is below the dew point, condensation of water vapor into water or ice occurs which can damage the insulation and sometimes cause rot in timbers.

Condensation does not occur in all walls, and, if moisture can escape from the wall to the air outside the house more readily than it can enter the wall from inside the house, there will be no accumulation of moisture within the wall even though condensation should occur at times. Installation of a "moisture barrier" near the inside surface of the walls, however, is often worth while as a precaution. The barrier should certainly be on the warm side of (that is, toward the house from) the insulation to retard the passage of water vapor toward the colder portions of the wall near the outside. Any barrier on the outside of the insulation is detrimental so far as condensation is concerned. Protection against rain is necessary, of course, but is a separate problem from that under consideration here.

Several products, such as some of the tarred papers, either designed or suitable for the purpose, are available on the market. Such materials are usually applied as barriers behind the laths and plaster or wall board, that is, between the plaster and studs. Ordinary building paper only is not considered sufficiently vapor resistant to serve as a vapor barrier.

Houses sheathed with metal or other vapor proof material on the outside require special consideration, usually involving ventilation of a space between insulation and sheathing to the outside.

Heating

No comprehensive and reliable test data are now available as far as we know by means of which a conclusive comparison of the

steam, hot water and warm air (including the winter air conditioning) heating systems can be made. Each has its proponents and the choice between the three is often based on personal preference. There is no reason why an efficiency or an economy obtainable with one of the three cannot be obtained with another. In practice, efficiencies undoubtedly differ considerably on account of the difference in the care and skill with which heating plants are installed and operated and no statistical study has been attempted to determine which of the three systems affords the greatest efficiency in the average case. The probability is that there are warm air systems with better efficiencies than some hot water systems or steam systems and some hot water or steam systems with better efficiencies than some warm air or winter air conditioning systems, etc. The conclusion is that the type of system is not the determining factor where efficiency is concerned and cannot be used as a basis for the comparison of efficiencies.

The United States Housing Authority has suggested some efficiencies for use in estimating fuel consumption. In practice, actual efficiencies may differ considerably from those suggested, as explained above, but the suggested efficiencies, with some assumed fuel prices and approximate fuel heating values, have been applied in computations and the results are tabulated below as a means of comparison. If actual prices and known efficiencies differ from those assumed, the tabulated costs of heat can readily be corrected by direct proportion in the case of fuel price and by inverse proportion in the case of efficiency.

Fuel	Firing	Heating Value	Fuel Cost	Eff	Heat Cost Cents per Million Btu
anufactured gas..	Conversion burner	600 Btu/Cu Ft	60¢/1000 Cu Ft	65%	154
anufactured gas..	Gas boiler	" " " "	" " " "	75%	133
atural gas........	Conversion burner	1000 " " "	50¢ " " "	65%	77
atural gas........	Gas boiler	" " " "	" " " "	75%	67
il (#1) ...	Pot or sleeve burner	136000 Btu/gal	10¢ / gal	60%	123
ituminous coal.......	Hand or stoker	14000 Btu/lb	$8/short ton	35 to 45%	82 to 64
nthracite coal.......	Hand or stoker	12000 Btu/lb	$10/ " "	35 to 45%	119 to 93

The efficiency estimate used in the following comes from another source:

)il (#2) ...	Mechanical burner	139000 Btu/gal	7¢/gal	65%	77

Electricity is included for the sake of completeness

The above figures are considered to apply to central domestic heating plants. Authoritative estimates of fireplace, fireplace grate, coal stove or wood stove efficiencies are not available. Our best information indicates that fireplace efficiency probably lies in the range from 10 to 25 percent. Stove efficiencies may be very good, that is above 50 or 60 percent. An unvented device such as a gas burning radiant heater must have a very high heating efficiency, above 90 or 95 percent, depending on the efficiency of combustion, since no heat is lost in the flue gas. A disadvantage here is, of course, that the occupants of the room must breathe and be surrounded by air contaminated by the products of combustion.

The efficiencies in the above table are intended to represent typical performance and not the best possible. The efficiencies practically attainable with coal can probably be improved 15 or 20 percent over those shown by careful firing and economical use of fuel and heat.

The heat value of wood depends greatly on its dryness. Data on air-dry wood contained in Kent's Mechanical Engineers' Handbook indicates that, in heating value, one cord of white pine is approximately equal to half a short ton of coal; a cord of yellow pine, to three-quarters of a ton, and a cord of white oak, to seven-eighths of a ton, etc.

First cost is a factor in choosing a heating system and, although some general statements on the subject can be made, the only means of deciding with any degree of exactness which system will be least costly to install in a proposed house is to compare cost estimates for the various types. Such estimates can be obtained from competing contractors in a position to survey the proposed job and guarantee performance.

The warm air heating system is more applicable to the "compact" than to the "rambling" type of house on account of the comparatively large size of the ducts. On the other hand, when heat is conveyed several hundred feet, as from a boiler house to a building, a steam line is usual because more heat can be economically conveyed through a pipe of a given size by means of steam than any other commonly used medium. Steam heating pipes in a house can be smaller than hot water heating pipes but the steam system may require control and safety devices, so that the hot water system may be the cheaper to install. Apparently the size range of dwelling houses is such that steam, hot water and hot air, can and do compete with each other as media for conveying heat through the distances involved in heating systems for such houses.

The above is written as if the case were clear cut and only a simple consideration of steam, hot water and warm air systems were necessary. In reality varieties of each of the three systems are in common use and a comparison in detail of all of them would be too long for presentation in a letter circular.

It is probable that the simplest type of warm air system is, on the average, cheaper to install than the simplest steam system and the simplest steam system cheaper to install than the simplest hot water system, but the control equipment essential to satisfactory heating in houses of various designs often alters this relation between first costs. In general, it is desirable that the heating equipment be designed or selected to suit the house.

Humidification

Humidification is very conveniently accomplished with warm air heating systems. Several types of humidifiers, including spray types and pan types, some completely automatic and some requiring manual filling and control, are available for use with such heating systems. Pans designed to hang on radiators are the only humidifying devices known to us which are ready made for use with steam or hot water heating systems.

There is reason to believe that excessive humidity in houses is more likely to cause difficulty than insufficient humidity. The first evidence of excessive humidity is likely to be condensation on windows which can result in streaked walls from water running from window panes, but a matter which can be more serious is condensation in the structure of walls, with resultant deterioration of timber, insulation, etc.

Reliable data correlating humidity and health are not available and no optimum humidity has been established by competent medical authority. The fact is, therefore, that winter humidification depends on personal taste. If one is convinced that he is more comfortable or healthier with, than without water vapor added to the air in his house, he should use a humidifier, taking due precautions against damage to the house such as that described above.

This subject is treated in more detail in University of Illinois Bulletin No. 230, entitled "Humidification for Residences", published by the University of Illinois, Urbana, Illinois, and in an article by C. P. Yaglou entitled "Physical and Physiologic Principles of Air Conditioning" which appeared in the Journal of the American Medical Association for May 15, 1937.

Computations

Methods for computing heat losses from buildings, or heat gains for air conditioning, are contained in the "Guide", handbook of the American Society of Heating and Ventilating Engineers of 51 Madison Avenue, New York, N. Y., and in various texts on heating and air conditioning.

In brief, it is now customary to compute heat losses by multiplying a factor, U, (Btu per hour per square foot per degree temperature difference) by a temperature difference between inside and outside, assumed for design purposes, and by the area of the exposed wall, window or other item under consideration. This operation is carried out for each exposed area in each room to estimate the heat loss for each room and the sum of the heat losses from the rooms is taken to be the heat loss of the house. To this are added estimated heat losses due to air leakage into the house and factors of safety, such as adding fifteen percent to the estimated heat loss of rooms exposed to prevailing winter winds, are sometimes applied.

Heat gain computations for summer air conditioning are made similarly, the heat flow being in the opposite direction, of course. Corrections for sun load and for any heat liberated in the house by lights, cooking and washing operations, etc., must be applied for summer air conditioning and the dehumidifying load is normally quite important.

Values of U for various building elements are contained in the reference mentioned above. This Bureau is now engaged in the experimental determination of U for some wall constructions of interest in connection with low cost housing and the results will probably be published in the near future.

The design temperature difference is usually obtained by assuming an indoor temperature of 70°F and an outdoor temperature 15 degrees F higher than the lowest temperature recorded for the region during the preceding 10 years. Design temperature data are contained in the ASHVE Guide and other references.

Radiators and Convectors

After computing the heat loss from a room as described above, it is necessary to find a heating device of suitable capacity. Radiators and convectors are usually rated in Square Feet Equivalent Direct Radiation, abbreviated EDR. A surface is said to have one square foot EDR when it has the ability to transfer 240 Btu/hour

to a room at 70°F with steam at 215°F, which corresponds approximately to one pound per square inch gage. This probably came about because, in the early days of radiator testing, some type or types radiators dissipated about 240 Btu per hour for each square foot of radiator surface. There is now some agitation for the abandonment of the square foot EDR in favor of the Mbh, meaning 1000 Btu per hour.

A "square foot of hot water radiation" is conventionally defined as an amount of radiator which will dissipate 150 Btu per hour.

To estimate the size radiator or convector to install in a given room the estimated heat loss from the room is divided by 240 to obtain the square feet EDR for steam or by 150 to obtain the square feet of hot water radiation.

Ratings of radiators and convectors are published by manufacturers in their catalogues and when the required capacity in square feet EDR or hot water radiation is known, one of suitable size can be chosen from a catalogue.

Radiators and convectors are now tested at the National Bureau of Standards as a part of the low cost housing program and, although the results in detail are considered confidential, it can be said that cast iron radiators and top outlet convectors are fairly conservatively rated in catalogues but that front outlet convectors should, in some cases, be chosen some 20 percent oversize if they are to develop required capacity on a condensate basis.

There is no reason to suppose that the cost of heating is materially higher with convectors than with radiators or vice versa. The first cost of convectors is likely to be the higher. Adequate insulation, say an inch of typical commercial insulation, should be installed behind convectors set into exposed walls.

Boilers

Boilers, like radiators and convectors are rated in square feet EDR or in square feet of hot water radiation. It has been the practice to install heating boilers with ratings from 1-1/2 to 2 times the estimated heat loss to allow for rapid warming up of the system and the losses from the piping.

Some new boiler codes have been published by the Institute of Boiler and Radiator Manufacturers of 60 East Forty Second Street, New York, N. Y. Boiler ratings under these codes, to be known as

I-B-R ratings, are in terms of actual connected radiation. Allowances have already been made for piping loss and warming up in the ratings themselves.

Steel heating boilers are usually rated in accordance with the recommendations of the Steel Heating Boiler Institute, Middletown, Pennsylvania, and these recommendations are contained in National Bureau of Standards Simplified Practice Recommendation R 157-37. The bases for such ratings are assumptions of a ratio of 14 to 1 between radiator surface (EDR) and heating surface for hand fired boilers and of a ratio of 17 to 1 between radiator surface (EDR) and heating surface for mechanically fired boilers.

Reliable data on which to estimate the relative durability of cast iron and steel boilers or furnaces are not available. Cast iron boilers and furnaces are generally of thicker metal than those of steel and have the reputation of being more resistant to corrosion but also of being more subject to cracking than such devices made of steel. This means that for any given case, it cannot be definitely known in advance that a boiler or furnace of one material will outlast one of the other material. The probability is that a steel boiler will require attention earlier than one of cast iron. The tubes in steel boilers must sometimes be replaced on account of corrosion. Some engineers do not favor boilers with the tubes welded in because tube replacement in such boilers is difficult.

Warm Air Heating Systems with Natural Air Circulation

Much of the design data on warm air heating systems was developed by the Engineering Experiment Station of the University of Illinois, Urbana, Illinois, and the National Warm Air Heating and Air Conditioning Association of Columbus, Ohio.

In natural circulation warm air systems, a separate duct from the furnace to each room is usual. This duct is composed of a "leader" in the basement which connects the furnace to a vertical "riser" or "stack" which delivers warm air to the register in the room. Systems are sometimes designed on the assumption that leaders will deliver the following amounts of heat for each square inch of their cross-sectional area:

First floor . . .	111 Btu per hour
Second floor . . .	166 " " "
Third floor . . .	200 " " "

The course of the duct should be as direct as possible. Leaders over 8 feet long may require special consideration. This explains why the furnace for this type of system is usually placed at or near the middle of the basement. Stacks for upper floors should have at least 70 percent as much cross sectional area as their respective leaders. The cross sectional area of the return duct should equal or exceed the sum of the areas of the heating ducts.

Warm Air Heating Systems with Forced Air Circulation

Small forced circulation warm air systems with individual ducts of approximately equal length can be designed on a basis of equal air velocities in the various ducts. A cubic foot of air at 150°F will deliver nearly 1.25 Btu to a room at 70°F. On this basis a duct of one square foot cross sectional area with an air velocity of 500 feet per minute will deliver about 500 x 1.25 x 60 = 37,500 Btu per hour under the same conditions. A fan or blower must be installed to furnish the necessary air motion.

The above will give the home owner an idea of the design of warm air systems. The problem is complicated when the system is large, when the ducts are of unequal length and when the heat losses from the ducts themselves must be considered. Those interested in the details can consult the "Guide", handbook of the American Society of Heating and Ventilating Engineers, "Gravity Warm Air Heating" and "Winter Air Conditioning - Forced Warm Air Heating" by the National Warm Air Heating and Air Conditioning Association and various texts on the subject.

Oil Burners

Government publications on oil burners are Agriculture Department Circular 406 "Oil Burners for Home Heating" and National Bureau of Standards Commercial Standard CS75-39 "Automatic Mechanical draft Oil Burners Designed for Domestic Installation". Copies of these publications are available from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

Agriculture Department Circular No. 406 contains some discussion of the various types of oil burners, gun, rotary, pot, etc., but it does not contain comparisons by make or brand.

NBS Commercial Standard CS75-39 contains some specifications for oil burner construction and performance and a list of acceptors of the commercial standard. The specifications were established

at a meeting held under the auspices of the Trade Standards Division of this Bureau at which users, dealers and manufacturers of oil burners were represented.

A specification contained in the Commercial Standard is that the burner shall, when in ordinary service, produce at least 8 percent carbon dioxide in the flue gas without visible smoke at the chimney outlet. Some service men and FHA inspectors now equip themselves with Orsat or other suitable apparatus for making flue gas analyses.

The National Bureau of Standards has no data on which the various makes or types of oil burners can be compared. Good oil burner performance is dependent upon proper baffling in the fire box, sufficient boiler heating surface and in general upon the care and skill with which the burner is installed and operated. Make, selling price, and type of burner are therefore not the only criteria of performance. Tests and inspections for compliance with the above Commercial Standard are made at an independent laboratory, not by this Bureau. The Commercial Standard applies to both the rotary and the gun types of burners.

Stokers

A Government publication on stokers is National Bureau of Standards Commercial Standard CS48-34 "Domestic Burners for Pennsylvania Anthracite".

Some information on stokers may be obtainable from the Stoker Manufacturers Association, 307 North Michigan Avenue, Chicago, Illinois.

Some recommendations on anthracite stokers are contained in publications of the Anthracite Industries Laboratory, Primos, Pennsylvania, and practical solutions of coal and ash handling problems are available from the same source.

Air Conditioning

Air conditioning can be defined as the preparation of the air in a space for human comfort. In this sense the problem naturally divides itself into two parts: Winter air conditioning, for which heat is added to the air and summer air conditioning, for which heat is taken from the air.

Since the equipment now generally called winter air conditioning equipment prepares the air before it enters the conditioned

space, it is perhaps more properly termed air conditioning equipment than are stoves, radiators, convectors, etc., which emit heat by convection and radiation in the occupied space.

Winter air conditioning equipment has come to signify some form of forced-circulation warm air system, usually with humidifiers, air filters and automatic controls. The remarks above under Heating are applicable to it.

There are a number of ways in which comfort conditions in houses can be improved in summer. People have been accustomed to fairly heavy expense for heating for a long time but since they have been without artificial cooling until comparatively recently there is a reluctance on the part of many to accept the expense necessary for complete air conditioning.

A complete domestic air conditioning plant would include a refrigerating machine and a means of using the machine to cool and dehumidify the air in the house. An obvious application is to install the machine in conjunction with a forced circulating warm air system and to use the same ducts for heating in winter and cooling in summer. It is probable that ducts and/or the circulating fan which are designed particularly for heating will not be entirely proper for cooling the house and the system should be designed with this in mind. The chief expense is likely to be the first cost of the refrigerating machine and the cost of power and perhaps water necessary to its operation. As a very rough guess, this expense, to equip a six or eight room house, would amount to from $500 to $1000 for the equipment and the cost of sufficient power to operate a 3 to 5 horsepower motor. Water to cool the condenser may be a considerable item. Some experiments with equipment of this type in the Research Residence at the Engineering Experiment Station of the University of Illinois are described in a paper entitled "Investigation of Summer Cooling in the Warm Air Research Residence". The price is one dollar.

If a householder is so fortunate as to have available a copious source of cool water such as a well or spring he can utilize a system similar to the above without purchasing and without the operating expense of the refrigerating machine. To be useful the water temperature should be 60°F or below and the flow should be, say, from 5 to 15 gallons per minute or more for houses, depending upon their size. Such water can be effectively used, also, in a simple unit cooler and home made unit coolers have been constructed of automobile radiators, through the tubes of which such water flows or is pumped and between the fins of which air is forced by suitable fans or blowers. Such radiators, if used, should be installed with their fins inclined to facilitate draining

and with drip pans or drains to dispose of water condensed from the atmosphere.

Unit air conditioners suitable for single rooms are on the market and are less expensive than equipment for a whole house. Descriptions can be obtained from the several manufacturers and such equipment is covered by Federal Specification OO-A-361, "Air-Conditioning-Units (Room Coolers); Electric-Motor-Driven, Portable." Copies are available from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

A convenient air cooling device useful in dry climates is the direct evaporative or desert-type cooler. It consists essentially of a mass of excelsior, say a couple of feet square, kept wet by a water drip and backed by an electric fan to force the air through the wet excelsior and into the house or occupied space.

Some information on the subject has been obtained from the Southern Sierra Power Company, Riverside, California.

The cooling action results from the evaporation of the water from the excelsior, possible in regions of low humidity. The probability is that the device would be practically useless in a region of the United States east of the Mississippi.

A widely practicable means of improving comfort conditions in summer is the use of an attic ventilating fan, an extension of the very old practice of ventilating for cooling by simply opening windows. The equipment usually consists of a fan, from 1-1/2 to 4 or 5 feet in diameter depending on the size of the house, installed in a window, door or other opening in the attic to exhaust the air out of the house. Open doors, and sometimes grills installed for the purpose, permit passage of air from other parts of the house to the attic. A usual practice is to start the fan during the early hours of the evening and so take advantage of the temperature drop which usually accompanies night fall. With the fan operated only at night and the house closed during the day, the house may be kept cooler than the average temperature out of doors. Manufacturers of fans designed for this purpose recommend sufficient fan capacity for one air change in the house in from 2 to 5 minutes. This will result in a breeze through any open window or door. Lesser capacities would also be of some benefit. A small ventilating fan in the kitchen to expel heat and vapor incident to cooking often materially improves comfort conditions in the whole house.

It is important to make all openings through which the air must pass ample in size. Considerable volumes of air can be moved at low speed with little power.